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SPACECRAFT STUDY THE SOLAR SYSTEM

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16. Abstract
Developments are described in the achievements of Soviet and American space scientists in studying various celestial bodies by spacecraft. Particular attention is devoted to information gathered on the Moon, Mars, Jupiter, Mercury, Venus and Saturn.

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SPACECRAFT STUDY THE SOLAR SYSTEM

G.A. Skuridin

> . . . Nature is like a woman who loves to dress up and who, showing under her finery first one part of her body and then another, gives her persistent admirers some hope of learning it all at some time. /27*
>
> D. Diderot

Certain stages in the development of human culture are reflected in the century-old history of the study of the Solar system. However, the contemporary stage in the /28
study of the Solar system is not repetitious either in its technical scale or in its obtained results. Automatic spacecraft have directly approached many planets in the Solar system and have made soft landings on the Moon, Venus and Mars. The flights of the American astronauts to the Moon and their landing on its surface, the work on the Moon of the self-propelled Soviet vehicles, the delivery to the Earth by men and automatic machines of lunar soil, and the placement by American astronauts of numerous scientific instruments have become the greatest events in the history of mankind.

The flights to the Moon required a certain level of development of rocket and space technology and the creation of new, more powerful carrier rockets, control and orientation

*Numbers in the margin indicate pagination in the foreign text.

systems, and a more modern set of scientific instruments.[1] The first space rocket to reach the environs of the Moon was the Soviet rocket launched on January 2, 1959.

The far side of the Moon was first photographed in October 1959 by the Soviet automatic station "Luna-3", which began the direct study of the lunar surface, and particularly cartography of the surface. The Soviet space vehicle "Zond-3" successfully photographed the side of the Moon invisible from the Earth. Fundamental data on the lunar surface was obtained as a result of the transmission to the Earth of panoramic pictures by subsequent Soviet automatic space stations, the "Luna-9" and "Luna-13," as well as by the American "Ranger" and "Surveyer" space vehicles.

Interpretation of the photographs exposed many features of the structure of the far side of the Moon: the continental character of the surface with high crater density in the absence of vast ocean regions. A unified system of selenographic coordinates on both lunar hemispheres was created on /29 the basis of the obtained photographs. This system was subsequently made more precise by further launches to the Moon

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[1] In our country a great deal of attention has been given from the very inception of space flights to a program of research on the Moon and the planets of the Solar system. The priority achievements in the field of research on the Moon and planets were reached owing to the magnificient contribution to the development of rocket-space systems by our outstanding structural engineers headed by academicians S.P. Korolev and V.P. Glushko and by corresponding member of the USSR Academy of Sciences G.N. Babakin. The outstanding Soviet scientist, Academician M.V. Keldysh, had overall responsibility for the program of space research, and particularly research on the Moon and planets.

of automatic space stations and manned spacecraft. Circular panoramas of the lunar surface obtained at various solar altitudes made it possible to see the relief of the Moon as a person would see it standing directly on the Moon (resolution of the photographs was on the order of 1 mm).

A huge contribution to the interpretation of the photographs was made by Soviet scientists Yu.N. Lipskiy and A.I. Lebedinskiy. The surface of the Moon proved to be very rough and had many tiny depressions and hillocks. Individual rock-like formations approximately 15 cm and larger in size were scattered throughout the surface. In one of the pictures transmitted by the Surveyer-1 station, for example, a large rock approximately 0.5 m in size was seen. Specific lunar formations were found and named talassoids ("sea-like").

On February 3, 1966, the Soviet automatic space station "Luna-9" made the first soft landing on the surface of the Moon to the west of the Reiner and Marius craters in the Oceanus Procellarum, and the first artificial satellite, the Soviet "Luna-10" station, first appeared on the Moon on April 3 of the same year. The first and subsequent soft landings of space vehicles on the Moon made it possible to determine many of the mechanical and other characteristics of the lunar surface. It turned out that the surface of the Moon is covered with a layer of poorly-bound, consertal material that is grayish-brown in color. A more friable, thin layer of unique lunar dust was found on the near side of the lunar surface.

This dust was raised by the gas jets of the retrofire rockets when the space vehicles landed on the surface of the Moon. It should be noted that the lunar dust differs substantially in its properties from terrestrial dust. The entire surface of the Moon in under special conditions that cannot at all be found on the Earth: a space vacuum, constant blowing of a solar wind, the effect of ultraviolet radiation, meteorite bombardment and a number of other factors. The result is that tiny particles of lunar soil can, under the influence of intermolecular forces, adhere into larger particles (they can adhere upon contact to the surface of other bodies, substantially changing their optical properties). At the /30 same time, the adhering formations can crumble into smaller pieces and particles under the mechanical effect. Similar phenomena were observed during the motion of the "Lunokhod-1", for example, which "crushed" large clumps falling in its path.

Important data on the nature and structure of the Moon was obtained from an analysis of its gravitational and magnetic fields and from an analysis of lunar seismicity. The gravitational field of the Moon is felt on the Earth when observing the high and low tides in the oceans and certain types of disturbances in the Earth's atmosphere, for example. The Moon also influences the Earth's rotation, and more precisely the precession and nutation of the Earth's axis. The magnitudes of precession and nutation are connected by a certain dependence with the mass of the Moon. By determining the constants of precession and nutation using astronomical methods, it is possible to determine the mass of the Moon. From an analysis of the gravitational field of the Moon it is possible to determine the level surface of this celestial body, i.e., the surface limiting the volume occupied by the Moon and in shape forming the so-called selenoid. Observations of the physical libration of the Moon led scientists to the conclusion that the Moon is a heterogeneous body, i.e., the Moon is not in a state of hydrostatic equilibrium, and, consequently, the selenoid cannot have a spherical shape; the results of the American astronomer G. Eckert even led to the known "paradox of the empty Moon," i.e., an anomalous fall in density with depth.

The flights of the "Luna" and "Ranger" automatic space stations and the "Mariner" and "Zond" type space vehicles, whose motion was influenced by the Moon's gravitational field, made it possible to subs tially pinpoint the mass of the Moon, whose value is now taken as equal to approximately 7.35×10^{25} g (which is approximately 81.303 of the Earth's mass). Beginning with the flight of the "Luna-10" automatic space station and subsequent lunar artificial satellites, the gravitational field of our nearest celestial neighbor was the subject of a detailed study. The Soviet scientist E.A. Akim as early as 1966 constructed the level surface of the Moon touching the actual physical surface in the visible center of the lunar disk based on the disturbances of the motion of the "Luna-10." His results attest to the fact that the gravitational field of the Moon is asymmetrical relative to its far and near sides, and the shape of the selenoid is pyriform and prolate on the far side. From an analysis of the measurement data Akim determined the so-called fixed moment of lunar inertia, knowledge of which makes it possible it draw definite conclusions relative to the density distribution inside the celestial body.

It is known that for a planet with a constant density the fixed (or dimensionless) moment of inertia is equal to 0.37 ± 0.04. Processing of analogous data from the American "Lunar Orbiter" satellites led to a value of $0.393 + 0.014$, i.e., even closer to 0.4 (which corresponds to a homogeneous Moon). Thus, the "paradox of the empty Moon" proved erroneous. Moreover, a homogeneous Moon must have a selenoid shape in the form of a triaxial ellipsoid, and, as Akim demonstrated, the shape of the solenoid is actually pyriform. This caused certain difficulties in the conception of the structure of the Moon's gravitational field.

Irregularities in the satellite velocity were noticed in 1967 during the flight of the American artificial moon satellite "Lunar Orbiter-5": when it flew over round lunar seas, its velocity increased by approximately 0.5 m/sec. Analysis of the motion of lunar satellites permitted the American scientists P. Mueller and V. Siogren to make an important discovery in 1967--they found so-called mascones, i.e., excess concentrations of mass near the lunar surface (mass concentration). In most cases these mass excesses are associated with seas of an impact origin. For example, according to estimates the mass excess in the Mare Imbrium amounts to about 5 x 10^{14} tons.

In addition to the positive gravitational anomalies, Mueller and Siogren point to the existence of a negative anomaly in the Sinus Iridum as an actual phenomenon, as well as in the Ptolemaic and Albategnius lunar walled plains, which were obtserved during the flight of the Apollo-12. The detection of gravitational anomalies in places of very ancient lunar formations attests to the fact that the Moon is a very solid body with lower temperatures than on the Earth. Calculations are currently being made for the entire lunar sphere, which indicate that even larger mascones than in the /32 Mare Imbrium should be found in the Mare Orientalis and Mare Marginis; also, a mascone with an excess mass five times greater than the mascone mass in the Mare Imbrium is located approximately in the center of the far hemisphere. It should be emphasized that the indicated gravitational anomalies are in full accordance with the structure of the Moon's gravitational field as revealed from an analysis of the flight of the Luna-10. At the same time it should be noted that certain characteristic features of the lunar gravitational field can be explained not only by mascones. Thus, the gravitational anomaly on the far hemisphere of the Moon can be explained by the great thickness of the lunar crust.[1]

At the present time it is still difficult to speak of a complete understanding of all the detected gravitational phenomena on the Moon: there exists a number of interesting hypotheses, but they all meet with one difficulty or another, whose solution is connected with further study of our celestial satellite.

The study of the Moon's magnetic field began in September 1959 with the flight to the lunar surface of the Soviet automatic space station Luna-2. The first and the main conclusion which the Soviet magnetologists N.V. Pushkov and Sh.Sh. Dolginov were able to make from an analysis of the indices of the magnetometer during its operation on a portion of the flight (comprising several fractions of the lunar radius) was the following: if the Moon can possess a magnetic field, then the effective magnetic moment of the Moon must be less than one ten-thousandth of a part of the Earth's magnetic moment. The Moon at this time was in the loop of the Earth's magnetosphere and was thereby screened from the solar wind and "frozen into" its magnetic field.

Nevertheless, the absence on the Moon of a true magnetic field required confirmation, especially after finding wake trails of the Moon at a distance of about 140 lunar radii

[1]Very interesting observations were made using the laser altimeter of the Apollo-15. It turned out that the regions of the visible digit of the Moon lie approximately 2 km lower and the invisible hemisphere is raised relative to the sphere with a center in the center of the mass.

on the American Explorer-18 satellite in 1963. In this regard the magnetic measurements made in 1966 on the Luna-10 space station played a no less important role than those /33 on the Luna-2 space rocket. During the flight of the Luna-10 around the Moon at altitudes of about 350 km and above, the magnetometer recorded a field with an intensity of up to 9-16 gammas. There was no dependence on the distance to the lunar surface. No shock wave front was found in front of the Moon from the side of the Sun. These data again proved the absence on the Moon of a true magnetic field. At the same time, the measured magnitudes of the magnetic field intensity on the Moon exceeded the values of the intensity of the interplanetary magnetic field and were clearly associated with space magnetic activity.

Prolonged measurements (beginning in 1967) on the American lunar satellite Explorer-35 confirmed the data of the Soviet vehicles and indicated that there is no true magnetic field on the Moon equal to at least 10^{-5} of the value of the Earth's field.

This conclusion is completely confirmed by the nature of the interaction of the solar wind with the Moon. The Moon does not have a magnetosphere and a non-collison shock wave is not formed near the Moon. The Moon is a non-magnetic, electrically non-conducting (dielectric) body around which a supersonic plasma flux flows freely. The surface of the Moon thereby absorbs and neutralizes solar wind particles.

A recess in which there is no solar plasma is formed behind the Moon as a result of the flow of the solar wind around it. The interplanetary magnetic field is disturbed by the Moon. As N. Ness pointed out, in the plasma recess (in the shadow region) it increases, and along the edges of the recess (in the semi-shadow region) it diminishes.

The first magnetic measurements on the lunar surface itself, begun by the lunar expeditions of the Apollo-12, -14, and -16 spacecraft, can, in the opinion of the heads of these experiments (the Americans P. Dale and K. Parkin), "be looked upon as a modern reiteration of the first planetary magnetic experiment conducted by U. Gilbert in 1600," when it was proven that the Earth is a natural magnet.

At the landing site of the Apollo-12 in the Oceanus Procellarum the field was equal to approximately 35 gammas; a field of approximately 100 gammas was recorded near the /34 Cone crater during the expedition of the Apollo-14, and the magnetometer detected a field of about 313 gammas during one of the trips of the LEM of the Apollo-16. The found constant magnetic field of the Moon varies from point to point and is about 1% of the Earth's magnetic field. But it is not included in the classic picture of the global dipole field, and its origin is one of the fundamental problems of the history of the Moon.

Magnetic measurements on the surface of the Moon were conducted on the Soviet Lunokhod-2 self-propelled vehicle in the Bay of Le Monnier. The goal of these measurements was to establish the character of the magnetization intensity and the sizes of regions of uniform magnetization, and to expose its causes. The magnetic field in the Bay of Le Monnier was about 20-30 gammas and had its primary orientation of the horizontal component to the southwest; outside the craters the field had a basically southern direction, and the vertical component in the bay was directed upward.

Data of magnetic measurements in near-lunar space on the Explorer-35 and magnetic measurements on the surface of the Moon made it possible to estimate the intensity of the variable lunar magnetic field produced by electric currents flowing into the lunar interior. This field is connected with the entire Moon; it rapidly increases and diminishes and depends on the increase and decrease in the solar wind intensity. The character of induced electric fields is closely associated with the conductivity of matter in the lunar interior, and the conductivity itself depends on the temperature of the matter. A unique possibility is thereby presented for a determination of the temperature of the inner parts of the Moon.

The analysis (in a strong approximation, to be sure) indicated that the conductivity of the lunar interior is sufficiently low, and the corresponding temperature for the main mass of lunar rocks ranges from 600 to 1000°C. This attests to the fact that the Moon did not possess any molten, large core for a large part of its existence. Determination of the magnetic permeability of the Moon was an important feature of the magnetic measurements. This experiment was conducted simultaneously on the Explorer-35 satellite and on the lunar surface. The disturbance effect of magnetic /35 lines of force near the Moon should have been observed in the case of a significant lunar permeability. But such an effect was not detected, which attests to the low magnitude of magnetic permeability.

Thus, at the present moment we can conclude with certainty that the Moon does not possess the properties of a large magnet.

Seismic observations are the most powerful means of studying the structure of the planets, since the oscillations which are excited in the body of a planet encompass depths still unaccessible by any other research methods. Each focal point of seismic activity, surface or internal, is a unique light flaring briefly and illuminating the hidded depths of the planet. Therefore, the study of lunar seismicity was included among the most important methods used in the Apollo program.

On July 20, 1969, the crew of the Apollo-11 spacecraft delivered the first lunar seismometer to the surface of the Moon. The seismometer operated on solar batteries, and after 21 days went out of operation because of trouble in the control system. Subsequent expeditions placed seismic stations on the surface of the Moon with radio-isotope energy power sources designed to operate for 10 years.

A seismic network of four automatic stations of the same type has been functioning on the near side of the Moon since December 1972. The station's seismometers make it possible to register insignificant displacements of lunar soil (about 10^{-8} cm).[1]

Two types of seismic experiments are being conducted on the Moon: "passive"--recording of purely moonquakes, as well as oscillations caused by the falling of meteorites, and "active"--recording of oscillations produced by artificial explosions and shocks. Artificial shocks on the Moon were caused by the falling in a specified region of the third stage of the Saturn rocket and by the fall of the lunar section of an Apollo spacecraft; artificial explosions were caused by special charges with which the American astronauts were /36
equipped, as well as by grenades launches from the lunar surface upon command from the Earth.

The first, most unexpected result of the first seismic experiment was that the attenuation rate of elastic waves on the Moon was somewhat less than on Earth. The lunar section of the Apollo-12 spacecraft fell to the surface at a rate of about 1.68 km/sec. Its impact energy was approximately 3.36×10^{16} erg and seismic energy was about $(1.5-3) \times 10^{10}$ erg.

[1]Such sensitivity on the Earth is practically unrealizable because of different interference (industrial, atmospheric, ocean conditions, etc.). In this connection the Moon is an ideal seismic testing area, which makes it possible to increase the sensitivity seismometers even further.

The distance to the nearest seismometer (so-called epicentral distance) was equal to about 74 km. After 23 seconds a seismic signal set into motion the pendulum of the seismometer, and the first lunar seismograph was recorded on the Earth one second later. The recorded seismic signal reached a maximum approximately seven minutes after the collision of the lunar section with the lunar surface, and then slowly attenuated over the course of 54 minutes! An analogous phenomenon was recorded when the third stage of the rocket carrier of the Apollo-13 spacecraft fell to the Moon (velocity at moment of impact was about 2.58 km/sec, energy of impact was about 4.63×10^{17} erg, seismic energy was about 5×10^{12} erg, and epicentral distance was about 135 km). Signal attenuation continued for over 200 minutes! Similar phenomena were never observed on Earth. Lunar seismometers recorded all types of elastic waves: bodily (longitudinal and transverse) and surface.

Numerous different hypotheses were proposed to explain the detected seismic phenomenon. Many authors proceeded from specific physical conditions under which the lunar seismic experiment took place: the extreme heterogeneity of the upper part of the lunar soil, the presence in it of a huge amount of cracks (caused by the falling of meteorites), and large drops in daytime and nighttime temperatures. Moreover, thanks to the absence on the Moon of an atmosphere, free water spaces, and because of other physical features, losses of seismic energy because of inelastic thermal processes were quite insignificant.

The NASA heads of the seismic experiment primarily hold the hypothesis associated with the scattering of elastic waves on small irregularities, with a high seismic energy factor of the lunar crust--reciprocals of the attenuation coefficient. This magnitude is 10 to 100 times larger than in the Earth's crust. For this reason the seismic signal is stretched in time, and its behavior must be described within the framework of the so-called diffusion theory (the obtained theoretical curve of the amplitude change as a function of time was in good accordance with the experimental curve). The "diffusion" hypothesis was also tested by laboratory ultrasonic modeling of the distribution of elastic oscillations by using a steel plate in which grooves were randomly placed. In this case the obtained recording was also in good accordance with the lunar data.[1] /37

The crew of the Apollo-14 first conducted "active" seismic experiments on the Moon, i.e., essentially the first seismic reconnaissance of the structure of the upper layer of the lunar surface. A velocity cut up to a depth of 400 m in the

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[1]The duration of seismic signal attenuation can at the present time by apparently explained by the total effect of the scattering (dispersion) mechanisms and the repeated reflection when elastic waves pass into the upper layer of the lunar soil "plowed over" by meteorites, as a result of which the shock waves propogate almost without energy loss. This also explains the long "sounding" of the Moon.

Fra Mauro sea region.

The astronauts of the Apollo-16 conducted an "active" experiment in the continental region of Descartes. The results here were also unexpected: velocity cuts on the various regions proved close to one another (within the margin of error for determining the velocities of elastic waves and the cut thickness). This is apparently associated with the fact that the upper lunar layer primarily consists of regolith--tiny dust powder with almost identical density for the entire Moon. The same may be supposed for the lower layer, represented by breccia with high porosity and jointing.

Finally, the last expedition, the crew of the Apollo-17, also conducted a seismic experiment in the continental region (near Littrow).

The velocity cut of the lunar interior makes it possible to reveal certain laws in the deep structure of the Moon /38 (only in the region of the Oceanus Procellarum so far). An important consideration was the separation, as for the Earth, of the lunar crust, which consists of several layers. At first the velocities increase smoothly and then rapidly with depth. A sharp increase in velocity (by about 13% occurs at a depth of 25 km), and then at a depth of about 40 km it remains almost constant (about 7 km/sec). The boundary of the lunar crust and mantle is reliably distinguished at a depth of 65 km. If the extrapolation of the obtained data to other regions is correct, then the lunar crust have a greater thickness than that of the Earth. In their composition the lunar rocks in the upper 25-kilometer layer can be classified as basalts and those below as gabbro-norites. What occurs with the lunar matter at a depth of 25 km in the 3-kilometer layer has not yet been finally established (whether there occurs an exchange in the composition of the matter or whether the inner pores are closed as a result of the attainment of critical pressure in the matter, which leads to an increase in the distribution velocity).

On May 13, 1972, scientists witnessed unique phenomena: a meteorite about 3 m in diameter fell 140 km to the north of Fra Mauro. An almost 100-meter (in diameter) crater was formed on the surface of the Moon. This is a new, young cater on the Moon, study of which has exceptional significance: the history of ancient lunar craters can possibly be understood from this example. According to estimates, the depth of the crater (about 20 to 25 m) is a new window in the lunar interior, especially in connection with the study of the upper layer of its surface.

Waves from the falling of the meteorite in the upper mantle reached a velocity of about 8 km/sec. This makes it possible to speak of the fact that the boundary between the lunar crust and the mantle is apparently associated with the transition of matter to ultrabasic rocks of the olivine type.

A large meteorite also fell on June 17, 1972, in the region of the Sea of Moscow on the far side of the lunar surface. The waves from its impact passed through the entire thickness of the Moon; but on the near side the seismometers recorded only the longitudinal wave. This fact has fundamental importance for a study of the inner structure of the Moon, since it indicates that the Moon has a molten core through which transverse waves do not pass.

In addition to the "meteorite" signals, the seismometers recorded clear oscillations of true "moonquakes." Analysis /39 of these oscillations attests to the fact that inside the Moon they are subjected to reflections from different masses and surfaces. Consequently, huge heterogeneities of structure must also exist. The mechanical, or potential, energy of "moonquake" sources is scattered in the form of vibration energy and heat.

But the most striking thing in the study of "moonquakes" is the depth of their focal points. As a rule, the focal points are located at depths of 500 to 800 km. In the seismic sense the Moon is less active than the Earth. The maximum number of "moonquakes" so far recorded in the region near Descartes is about 3000 yearly. Their seismic energy is not great (about 10^9 to 10^{12} erg). As the Soviet seismologists A.V. Nikolayev and I.N. Galkin write, "this is equivalent to the light of the chandeliers in the Bolshoy Theater. Such 'light' with difficulty illuminates the Moon throughout, even taking into consideration its smaller dimensions as compared with the Earth." Most of the "moonquakes" coincide with the moment that the Moon is in perigee: at this moment the influence of the Earth's tidal forces on the Moon are at a maximum. Other periods of "moonquake" frequency were also found.

The absence on the Moon of an energy source such as convection in the mantle (the primary source of the Earth's tectonic activity) makes the Moon a calmer space body.

The head of the seismic experiments, American scientist G. Latham, has currently been proposing a working model of the velocity structure of the Moon.

1. The crust, whose thickness in the southeastern part of the Oceanus Procellarum is about 60 km.

2. The upper mantle, about 250 km thick. At the top of the mantle the longitudinal wave velocity is about 8.1 km/sec and about 7.8 km/sec below; transverse wave velocity is about 4.7 km/sec. The mantle has an olivine composition.

3. The middle mantle, about 300 to 800 km deep. There is a sharp boundary between the upper and middle mantles. It has been observed that high-frequency transverse waves pass through the middle mantle without noticeable attenuation. A layer of high conductivity (about 10^3 ohm-meters) is distinguished on the upper-middle mantle boundary.

4. The lower mantle--an "asthenosphere" is observed for strong attenuation or non-passage of transverse waves.

5. The nucleus is distinguished according to the time

lag in the path of longitudinal waves by more than 100 sec. /40
It should be pointed out that this is the only point on the hodograph. The nuclear mass is about 1% of the Earth's mass. It also proved possible to construct a picture of the thermal evolution of the Moon. The energy generated by the Moon's thermal flux is equal to approximately 10^{26} ergs a year, which is somewhat higher than the "moonquake" energy.

The lunar expeditions of the American astronauts on the Apollo spacecraft and the flights of the Luna-16 and Luna-20 automatic space stations delivered to the Earth about 400 kg of lunar soil samples from different regions of the Moon, including the mountainous regions (Luna-20 and Apollo-17).

Delivery to the Earth of lunar soil and the study of this soil open yet another surprising chapter in our knowledge of the structure, history, and origin of the Moon. The international character of research on the lunar material should be emphasized: the samples were delivered into the hands of scientists from many countries.

We have already said that the photographs of the lunar surface clearly pointed to the specific character of the structure of the lunar surface. American geologists have proposed that the surface layer of the Moon be called the regolith. Regolith is a special material consisting of brecciated rock: lunar dust, sand, and particles of bedrock. They contain "admixtures"--impregnated fragments of meteorites and various vitreous and vitrified particles. Precisely owing to these particles we see from an observation of the illuminated part of the Moon that the latter is not spherical, but rather flat (the "cat's eye" effect).

Lunar soils have currently been undergoing various tests under laboratory conditions: magnetic, thermomagnetic, optical, thermophysical, chemical, petrographic, minerological, etc.

The study of the chemical composition of lunar rocks has fundamental importance not only from the point of view of a study of the properties of lunar soil, but also of the overall evolution and origin of the Moon as a cosmic body. This study began by using a gamma-spectrometer mounted on the first artificial lunar satellite, the Luna-10 station. Analysis of the obtained data led a group of Soviet scientists (A.P. Vinogradov, Yu.A. Surkov and others) to the establishment of a fundamental fact: the amount of radioactive elements in lunar matter corresponds to their content in earth rocks /41 of the primary composition--basalts. No granite-like rocks were found on the Moon.

The first chemical composition of lunar rocks by element was determined by using the alpha-radiometer mounted on the Surveyer-5 space vehicle, and then by using a number of other spacecraft, including the Lunokhod-1 and Lunokhod-2. In their chemical composition the various regions differ from one another. The surface layer of the sea regions are reminiscent of terrestrial basalts in their content of chemical elements, but the so-called eucrites, a variety of stone meteorites, are the most similar to the surface layer.

More than 70 chemical elements have been determined by using mass spectral analysis. Silicon oxide is the largest single component of lunar soil (about 40 to 44%), followed by ferric and aluminum oxides and magnesium and calcium oxides. In mineral content lunar soil basically coincides with terrestrial minerals (pyroxene, plagioclase, olivine, ilmenite, and pure iron). Three minerals in lunar rocks proved to be quite new--pyroxmanganite, ferropseudobrookite, and chromous-titanous spinel.

Weight by volume of the upper layer of the lunar surface in the range of 15 to 20 cm is equal to 1.0 to 1.5 g/cm^2, and the angle of interior soil friction, or shearing strength, is from 30 to 40°: adhesion (in the upper several centimeters of the surface layer) is about 0.0013 to 0.0120 kg/cm^2; static supporting power at the same depth is on the order of 0.18 to 0.68 kg/cm^2, and one order lower on the surface itself. The porosity coefficient is about 0.87 to 1.01, which corresponds to the porosity of the material itself--about 46.5% to 50.1%.

Analysis of lunar soil made it possible to establish a number of other soil features, among which we note the following.

1. There are traces of erosion on the surface (rate of surface erosion of rocks is about 10^{-7} cm per year); on the other hand, no signs of water erosion were found.

2. A quite large amount of inert gas was observed,

especially argon-40.

3. The radiation age of rocks was $\gtrsim 10 \times 10^6$ years at a depth of several centimeters and $\geq 500 \times 10^6$ years at a depth of about 1 to 2 m.

The age of lunar basalt rocks from the Oceanus Procellarum and the Mare Tranquillitatis was equal to approximately 3.5 billion years. But, as is well known, basalt is formed from "remelting" in the lunar interior, i.e., a certain period in the development of the Moon must have passed before the formation of the Oceanus Procellarum and the Mare Tranquillitatis. This is one of the principal dates in lunar history. The primordial age of the Moon itself is set as approximately 4.5 billion years. It was determined by the age of a rock from the region of the lunar Apennines, for which it was named a "sample of the day of creation." Thus, the age of the formation of the Moon approaches the age of the Earth. /42

4. Carbon content in the samples was about $(50\text{-}25) \times 10^{-5}$ g/yr.

5. No signs of biological material were detected in the moon rocks.

6. Heat conductivity of the dust layer was approximately 1000 times lower than in bedrocks (granite, for example).[1]

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[1]The low thermal conductivity of the lunar surface was observed as early as 1942 by Academician V.G. Fesenkov, who wrote: ". . . not a single substation on Earth in which heat is distributed by molecular transmission can even remotely be compared with the material of which the lunar surface is made. In order to explain this it is necessary to assume that the

7. The amount of organic material is very small: about $(1-20) \times 10^{-6}$%.

8. The process of crystallization in the rocks took place from 1.7×10^9 to 2.7×10^9 years ago.

The question of the origin of moon rocks still remains difficult, but it is already possible to speak of the role of one or another process that took place in the history of the Moon. As Academician A.P. Vinogradov writes, ". . . the crystallized rocks on the surface of the lunar seas are of a single, basalt type, but differ somewhat in the content of certain chemical elements. Their content approaches that of primitive terrestrial basalts. The lunar seas are lowlands at one time inundated by volcanic lava. Basalt-type rocks are formed as the lowest-melting part during zone melting of /43
the inner matter of a planet. It can be assumed that the overall course of the differentiation between the matter of the Earth and Moon, and probably of other earth-type planets, proceeded analogously and reached different stages of development."[2]

The attainment of a second cosmic velocity and the creation of long-operating automatic space stations allowed scientists and engineers to arrive at a planned study of the

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materials on the surface of the Moon are in an extremely mellow state and that the transfer of heat takes place by direct radiation. Only pulverized matter in a vacuum can be characterized by such low thermal conductivity as exists for the lunar surface."

[2]Although the Moon is a satellite and not a planet, in its physical characteristics it is close to earth-type planets.

planets of the Solar system--Mercury, Venus, Mars, and in recent years the giant of the Solar system, the planets of Jupiter.

The first space vehicle, Venera-1, started toward Venus on February 12, 1961, and, passing a distance of about 270 million kilometers, became the first artificial solar satellite. The automatic interplanetary station Mars-1 was launched toward Mars on November 1, 1962. An entire series of automatic stations, both Soviet and American, was launched over the next 10 years toward Mars and Venus. The most remarkable of these were the Venera-4, -5, -6, -7 and -8, the Mars-2, -3, -4, -5, -6, and -7, and the Mariner-2, -4-, -5, -6, -7, -9, and -10.

The Venera-7 station, launched on August 17, 1970, reached the surface of Venus on December 15 of the same year and made a soft landing on the night side of the planet; the Venera-8 station, launched on March 27, 1972, first made a soft landing on the side of Venus illuminated by the Sun on July 22, 1972. Pendants with a bas-relief of Vladimir Il'ich Lenin and the State Coat of Arms of the USSR were delivered to the surface of Venus in honor of the 50th anniversary of the formation of the USSR.[1]

The Mars-2 and Mars-3 stations were launched toward Mars

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[1]A new launch was made on June 8, 1975, to Venus of the Venera-9 automatic station and on June 14 by the Venera-10. In October 1975 both stations reached the vicinity of the planet and became its first artificial satellites, and the descent vehicles of these stations made a soft landing and transmitted the first pictures to the Earth of the planet's surface.

in May 1971 and the Mars-4, -5, -6, and -7 were launched in July and August 1973.

The descent vehicle of the Mars-3 station entered the martian atmosphere on December 2, 1972, and by means of a parachute system made the first landing on the surface of the /44 planet, and the Mars-2 and Mars-3 stations themselves became the first artificial satellites of Mars. Because of a malfunction in one of the spacecraft systems, the propulsion system of the Mars-4 system did not switch on, and the station flew past the planet by a distance of 2200 km. The propulsion system of the Mars-5 system was turned on on February 12, 1974, as a result of which the station went into orbit as a satellite of Mars. During the approach to Mars a descent vehicle was separated from the Mars-6 station; this vehicle then was put into a collision trajectory with Mars. Descent onto the planet was accomplished by a parachute, and the transmitted information was recorded on the Earth through the Mars-6 station.

American space vehicles of the Mariner type also reached Venus and Mars at different times during the last decade. On December 14, 1962, the Mariner-2 flew past Venus by a distance of about 41,000 km from the center of the planet. On October 19, 1967, the Mariner-5 reached the vicinity of Venus, and on February 5, 1974, this was reached by the Mariner-10, whose trajectory, as a result of Venus' gravitational field, changed such that the subsequent flight of the station continued toward Mercury.

On July 15, 1965, the Mariner-4 space station passed the surface of Mars at a distance of about 10,000 km. After passing Mars the Mariner-4 went into a heliocentric orbit around the Sun, and its association with the Sun was maintained for more than three years. The last radiocommunication session was on December 20, 1967, when the space vehicle again approached the Earth to a distance of less than 50 million kilometers. This made it possible to receive part of the information stored on board the space vehicle. On February 26 and 27, 1969, the Mariner-6 and -7 space vehicles were launched toward Mars. The new space vehicle Mariner-9, which went into orbit around Mars on November 14, 1971, was launched on May 30, 1971.

Analysis of the measurements made on the Venera stations made it possible to obtain fundamental data on the chemical composition of the venusian atmosphere (A.P. Vinogradov, Yu.A. Surkov, et al.), as well as on the thermodynamic parameters of the atmosphere: pressure, temperature, density /45
(V.S. Avduyevskiy et al.), which enabled the construction of a model of the planet's atmosphere (V.I. Moroz et al.).

It was experimentally proven that the atmosphere of Venus primarily consists of carbon dioxide (about 90%) with a slight addition of oxygen (about 0.1%) and nitrogen (about 2%); the temperature on the surface of Venus reaches about 750°K, and the pressure about 90 atm. The temperature gradient in the venusian atmosphere is about 8 to 8.5°K/km. Daily temperature fluctuations on Venus as a result of the significant thermal capacity of the atmosphere is about 12°C, and the temperature drop between the pole and equator is equal to about 18°C. Temperature drops by altitude are very great: the temperature at the summit of a five-kilometer mountain is 40°C lower than an its base.

Measurements of wind velocity at the landing site of the Venera-8 station yielded the magnitude of approximately 0 to 2 m/sec and a direction from the terminator to the day side, i.e., to the side of the planet's rotation. However, wind velocity increased sharply with altitude, reaching a hurricane velocity of about 50-100 m/sec at an altitude of 45-55 km.

It is supposed that the significant wind velocities are associated with the four-day period of circulation of the upper layers of the venusian atmosphere previoudly found from ground observations. The presence in the venusian atmosphere of a temperature gradient in the meridianal, equatorial, and vertical directions creates a very complex picture of the circulation current in the horizontal and vertical planes. Attempts are currently being undertaken at theoretical modeling of the "weather" on Venus. However, a final testing of these attempts can be carried out by a more detailed study of the cloud cover of Venus using space vehicles.

In this regard the photographs obtained from the Mariner-10 during its flight around Venus in February 1974 brought important data on the circulation of the planet's atmosphere. The photographs showed that Venus is covered by dark and noctilucent cloud belts whose location coincides with the planetographic parallels or at a certain angle to them. The four-day period of circulation of the upper layers of the atmosphere was confirmed; three cloud layers were able to be detected--at 40, 60, and 80 km from the surface.

Powerful circulation currents are directed in a spiral /46 from the equator to the poles, whose dividing point is an area of turbulence (the "eye of Venus") located at the subsolar point (in the equatorial zone) with a diameter of about 1600 km. Clouds floating from the equatorial zone rush toward the poles and merge with the famous polar clouds at 50° north and south latitude.

As Henry T. Simmons writes, "these cloud rings and clearly distinguished 'cap' over the south pole in all probability comprise a whirlwind in which hot gases extracted from the equatorial zone cool off, condense and settle in the lower part of the atmosphere, from which they again fall into the equatorial zone. New data on the upper layers of the atmosphere somewhat contradict the fact that high temperatures of the planet surface are caused by the hothouse effect. The actual cause of this may be the dynamic process by which the Sun directs its energy to the constant high-pressure zone--"oko," which also encompasses the surfaces of the day side of the planet and distributes its heat throughout the planet, thanks to a well adjusted scheme of meridional atmospheric circulation."[1]

Atomic carbon, oxygen and hydrogen were detected in the upper atmosphere of the planet from the data of the Mariner-10, and the presence of ammonia was detected in the venusian atmosphere upon the landing of the Venera-8 (content by volume was about 0.01 to 0.1%).

Above 60 km, according to measurements in the infrared band, the temperature increases by 2° with each kilometer. The lowest temperature (about 160°K) was recorded at an altitude of 100 km; the temperature in the region of the exosphere varies from 300 to 900°K. Photometric measurements of illumin- /47 ation of the atmosphere of Venus were first made on the Venera-8 station. The measurements showed that, despite the significant attenuation of the solar light, part of it reaches the surface of the planet and there are differences in the degree of illumination during the day and night. Illumination of 3600 ± 1000 lux at an altitude of 49 km drops

[1]The circulation picture of the upper layers of the venusian atmosphere detected in the photographs was close to the scheme which the English astronomer G. Hadley had proposed as early as 1735. According to Hadley's model, the planet receives considerably more heat at the equator than at the poles. As a result, the hotter air along the spirals is shifted toward the poles. All the conditions for realization of a similar scheme are present on Venus, in contrast to the Earth: the planet's axis of rotation is almost perpendicular to the orbital plane, true rotation is slow, there are no continents and oceans, and there is a slight drop in night and day temperatures. The temperature gradient in the "equator-pole" direction is therefore sufficient for the development of circulation of the venusian atmosphere.

to 350 $\pm$ 1000 lux on the surface. Visibility on the surface of Venus is about 1 km. These data pertain to the venusian morning.

The Venera automatic stations and the Mariner-2, -5, and -10 space vehicles made it possible to obtain many new data on the physical properties of the planet and its surroundings. A gamma-spectrometer mounted on the Venera-8 (A.P. Vinogradov, Yu.A. Surkov, et al.) made it possible, according to preliminary calculations, to establish that the rocks forming the surface of Venus at the station's landing site are similar to granite rocks on Earth. The density of the surface layer at the landing site was about 1.4 g/cm^3, which corresponds to friable rocks.

Magnetometers mounted on the Mariner-2, -5, and -10 stations and a number of the Venera stations did not detect a magnetic field on Venus. But the moments that the vehicles passed the front of a non-collision shock wave near Venus were recorded as they approached the planet at various distances from it by magnetic and plasma measurements (Dolginov, Gringauz). This is obviously connected with the appearance of a magnetic field of induced currents in the conducting ionosphere of the planet with a maximum electron density at an altitude of about 150 km. The electric field of the solar wind, penetrating the venusian atmosphere, induces a current in it whose magnetic fields, interacting with the solar plasma, form a "pseudo-magnetosphere" on the day side. It is a hindrance to solar wind, on which the non-collision shock wave is formed.

The example with the non-magnetic planet, as is Venus, shows that solar wind can quite deeply penetrate the atmosphere of the planet. The interaction of solar wind with non-magnetic bodies having high-passing ionospheres is essentially a new field of space physics. Magnetic measurements near the planet Mars in 1965 on the American Mariner-4 /48
served as the first push toward an examination of this problem. The data of magnetic measurements (E. Smith, L. Davis, D. John) were not clearly explained at that time because of the detected shock wave near Mars.

M. Dryer and J. Heckman in 1967 expresses the hypothesis of the presence on Mars of a true magnetic field, and in 1970-72 J. Sprighter with coauthors examined the problem of the interaction of solar wind with the ionospheres of non-magnetic planets. The latter suggested that solar wind interacts directly with the ionosphere of Mars of Venus; gas dynamic pressure of the ionosphere is thereby counterbalanced by the dynamic pressure of solar plasma. The equilibrium boundary was named the ionopause. The formation of a shock wave front is possible as a result of this interaction.

Magnetic fields exceeding by 7 to 10 times the intensity of the interplanetary magnetic fields in martial orbit were determined in 1972 on the Mars-2 and Mars-3 spacecraft in the vicinity of Mars. Sh.Sh. Dolginov and colleagues came to the conclusion, on the basis of the obtained data, that the location of the shock wave front is best explained by the hypothesis of the existence of a true magnetic field on the planet. Two possible models were set against this hypothesis: a) the observed field--an interplanetary magnetic field of solar origin intensified behind the shock wave front (A. Dessler) and (b) the observed field was induced in the ionosphere by the electric field of the solar wind (F. Johnson, J. Midgely).

On the basis of the Mars-3 data, Dolginov and others pointed out that field intensification is not observed behind the shock wave front. It was not possible to check the role of the induction mechanism in the 1972 experiments. O.L. Veisberg and others expressed the supposition that the formaation of a so-called "ion pillow" adjacent to the ionosphere, which ensures the necessary balance in the pressures of the martial exosphere and solar wind, is possible behind the shock wave front. They suggested that the observed magnetic field can be induced by an electric field of solar wind in the "ion pillow" and in the martian ionosphere.

In February 1974 Dolginov and his colleagues continued /49 measurements of the magnetic field of Mars on the Mars-5 spacecraft. On the basis of their measurements, they came to the conclusion that the hypothesis linking the presence of a magnetic field with currents induced in the ionosphere does not take place. As a result of an analysis of the entire totality of the magnetic measurements they formulated their own conclusions as follows:

a) ". . . the planet Mars has a true magnetic field. Under the effect of solar wind this field acquires a characteristic shape: it is restricted on the day side and prolate on the night side. Field topology in the internal studied space is determined by the effect of the totality of internal and external field sources;

b) the topology of the lines of force on the day side at an altitude of 1100 km (Mars-3) and at altitudes of 2500 to 9000 km on the night side is best explained, if it is accepted that the axis of the magnetic dipole of Mars is inclined toward the axis of rotation at an angle of 15 to 20°. The north magnetic pole of the dipole is location in the northern hemisphere, i.e., the field of Mars is inverse in polarity to the geomagnetic field;

c) the magnetic moment of the martian dipole is equal to $M = 2.5 \times 10^{22}$ G-cm^3. . ."[1]

The Soviet space physicist K.I. Gringauz and his colleagues, having made a series of plasma measurements on the Mars-2, -3, and -5 spacecraft, came to the conclusion that the nature of the solar wind's flow around Mars is largely analogous to the

[1]At the same time it should be stated that a further study of the magnetic field of Mars is required in order to make a final decision on the problem of whether the measureable magnitudes are true magnetic fields of Mars or not. The American physicist N. Ness has expressed well-known doubts on this subject. Interpretation of plasma measurements in the near-martian space is no less complex than magnetic measurements.

conditions of its flow near the Earth.

Three zones were found in these measurements in which the plasma characteristics differ substantially from one another: a shock wave (zone 1), a transitional layer (zone II), and a plasma region (zone III) inside the tail of the martian magnetosphere. Areocentric distances (according to Gringauz) up to the subsolar point of hindrance and the shock wave front amount to $(4.6 \pm 1) \times 10^3$ and $(5.7 \pm 1) \times 10^3$ km respectively, i.e., for all intersections of the shock wave front the estimate of the mean altitude is equal to about 1200 ± 800 km. /50

On the basis of their own data, Gringauz and colleagues come to the conclusion that the totality of plasma measurements in zone III attests to the magnetic nature of the hindrance, whose flow by solar wind forms a near-martian shock wave.

Plasma measurements on the Mars-2, -3, -4, and -5 spacecraft were conducted by another group of Soviet scientists (O.L. Vaysberg et al.). As we have already said, this group also recorded the shock wave (zone I) but at a considerably smaller areocentric distance (about 4×10^3 km). Moreover, inside the transitional layer (zone II) there is a subzone (where a strong stagnation of the ion flux and ion cooling are observed--the "ion pillow", or boundary layer), which, in the opinion of these authors, separates the transitional region from the region of smaller fluxes and less energetic ions, and, finally, the plasma tail (zone III). The location of the shock wave front and the presence of a boundary layer make it possible to give another interpretation of the formation of the hindrance leading to the emergence of the shock wave itself. Such a "hindrance" can be the magnetic field induced by solar wind in the "ion pillow" and the martian ionosphere. The influence of the true magnetic field of Mars is very weak in this case.

The surface of Mars was photographed on the Mariner-4, -6, -7, and -9 at different times, as well as on the Mars-4 and -5 spacecraft. The first photographs of Mars were transmitted to the Earth from on board the Mariner-4 space station in July 1965. Analysis of the photographs of the martian surface obtained from the flight of the Mariner-4, -6, and -7 spacecraft past the planet opened a new picture of the structure of the martian surface that was unexpected for astronomers: it proved to be filled with craters of various sizes and was largely reminiscent of the surface of the Moon.

Three groups of fields differing in their structure can be distinguished on Mars: 1) fields filled with craters; 2) fields with chaotic structures; 3) non-structured zones.

The flight of the Mariner-9 to the planet Mars enabled /51
the reception of unique new data: by July 1972 almost all of Mars had been photographed with a resolution of up to 1 km. About 7000 photographs had been transmitted to Earth. A strong dust storm, which died out only in January 1972, arose as the Mariner-9 approached Mars (November 1971). As the American

astrophysicist K. Sagan writes, ". . . the martian dust storm serves as a natural experiment in the study of the influence on the climat of aerosol admixtures in the atmosphere of the planet. Such an experiment may prove decisive in estimating the theory of remote consequences to which industrial pollution of the Earth's atmosphere is being brought." In the opinion of Sagan, the strong displacements of dust on Mars can be explained if the magnitude of the wind velocity over the surface boundary layer is assumed to be up to about 70 m/sec.

Huge crater summits and the famous ring formation Nix Olimpica ("Olympian snows") among them were revealed in the photographs from the Mariner-9. On the basis of all these data American specialists came to the conclusion that the observed craters--those of volcanic origin and the Nix Olimpica--are the largest volcanic craters in the Solar system. At the present time the volcanoes are not active, but they are young (several tens or hundreds of millions of years old). In other words, volcanic activity on Mars did not occur geologically in recent times.

Detection of a huge rift valley stretching along the 80° martian longitude (thousands of kilometers long, about 100 km wide, and up to several kilometers deep) is included among the fundamental discoveries on Mars. Canals with tributaries, whose relief can be explained only by the action of water currents, were also found. This fact attests that the channel currents of water were on Mars comparatively recently.

Climatic changes apparently also occur on Mars (for example, possible ice formation on the caps). The Mariner-9 first made possible a careful study of the details of the martian satellites--Fobos and Deymos. Fobos and Deymos are old, rocky formations strongly pitted with craters. At the present time there can be no discussion of their artificial origin, as was previously suggested. /52 A study of the photographs of Fobos and Deymos permits a judgement with high reliability on the shock processes on the surface of the planets of the Solar system.

Evaluating the flight of the Mariner-9, Sagan writes: ". . . Mars is active geologically, and meteorological processes are active on it. Biological processes possible take place there. From the point of the upcoming 21st century, the flight of the Mariner-9 will become the event that first put us face to face with the real Mars, and not that boring Mars that was presented in the past. Once again, a single spacecraft changed our view of space."

Numerous data on Mars were obtained by using scientific instruments mounted on the Mariner and Mars spacecraft, especially on the Mars-6. Measurements of temperature on the surface of Mars showed that it varies strongly from noon to evening (from 5-12° at noon to -20-30° by evening). A temperature fluctuation on the order of 5 to 8° was also noticed downrange. The minimum temperature on the poles was -120°C. The main gas component of the martian atmosphere is carbon dioxide, and pressure on the surface is about 6.5 mbar. A small amount of water vapor (about 60 to 80 μm of precipitated water) was detected in the martian atmosphere, and the magnitude of moisture can differ by 2 to 3 times downrange. Soviet scientists (V.I. Moroz et al.) first succeeded in detecting in the normal midday atmosphere of Mars traces of ozone and a noticeable aerosol absorption even in the absence of dust storms. Direct measurements showed that the argon content in the planet's atmosphere can be about 0.35% (V.G. Istomin). The night ionosphere of Mars was detected in February 1974 during the radio-exit of the Mars-4 from behind the planet (with an electron concentration of about 5×10^3 cm^{-3} in the main maximum located at an altitude of 110 to 130 km). The tropopause altitude of Mars is about 25 to 30 km, the temperature gradient in the troposphere is about 2.5°K/km, the temperature of the isothermal stratosphere is about 150 to 160°K, and the altitude of the homogeneous atmosphere is about 7 to 10 km.

Estimates were made of the thermal and mechanical proper- /53
ties of martian soil by using infrared radiometer measurements on board the Mars-3 (V.I. Moroz, L.V. Ksanfomaliti). These properties are presented in the table.

Parameter	Mean value	Minimum value	Maximum value
thermal lag, $I = (k\rho c)$, $cal/cm^{-2} \cdot sec^{-1/2} \cdot deg^{-1}$	0.006	0.004	0.008
thermal capacity, sec, $cal/g^{-1} \cdot deg^{-1}$	0.19	0.17	0.21

Parameter	Mean value	Minimum value	Maximum value
density, σ, $g \cdot cm^{-3}$	1.2	1.0	1.4
thermal conductivity, k, $cal/deg^{-1} \cdot stoke^{-1} \cdot sec^{-1}$	1.6×10^{-4}	6.4×10^{-5}	3.8×10^{-4}
heat wave penetration depth, l, cm	4.4	2.7	6.5
mean particle size (crushed rock), d, cm	0.025	0.01	0.05

The shape of the planet was able to be precisely determined during the flight of the Mariner-9 in its orbit around Mars: it has a pear shape, its southern hemisphere is 3 to 4 km higher than the northern, and the lowest region is at 65° north latitude.

At the beginning of February 1974 the Mariner-10 flew past Venus and continued its flight to Mercury, the planet closest to the Sun. On March 29, 1974, the Mariner-10 reached Mercury and passed it at a distance of about 740 km. A number of experiments were carried out using scientific equipment: photography of the planet, measurement of the magnetic field, plasma measurements, etc. The Mariner-10 then moved in a heliocentric orbit, completing a full revolution around the Sun in 176 days. Since Mercury makes two revolutions around the Sun during this time, each 176 days the Mariner-10 approaches Mercury. The second approach occurred on September

21, 1974, and the third approach was on March 17, 1975. The repeated approach to Mercury for four hours made it possible to obtain 500 television pictures of the surface of the planet. Minimum distance during the third approach was about 210 km. About 650 pictures were received from the photography of the planet during the third approach, on some of which details of the surface of Mercury having a cross section of about 45 km could be distinguished. By the time of the third approach the Mariner-10 spacecraft had traveled on the order of 1.5 billion kilometers. /54

The Mariner-10 photographs permitted astronomers to gain a detailed knowledge of one more planet of the Solar system. It turned out that Mercury is more similar to the Moon than to Mars. Young craters on the surface of Mercury, similar to lunar craters, have sharp outlines and sharp swell ridges. There are formations that differ from lunar formations, however. A large number of concentric craters was observed on Mercury; even the most insignificant of them have central peaks. The formation of peaks bears witness to the presence on Mercury of a large inner core from which shock waves are reflected when meteorites fall. The fact that Mercury has an overall density close to that of the Earth speaks in favor of the core. According to preliminary data, inert gases--neon and argon, as well as helium--were detected in the planet's atmosphere. Magnetic measurements showed that the field of Mercury is insignificant (about 1% of the Earth's). A departing shock wave, as well as a magnetic vacuum analogous to the Earth's magnetosphere, are clearly fixed near Mercury. The maximum magnetic field is about 98 gammas was observed when the Mariner-10 approached at a distance of about 700 km (N. Ness et al.). Plasma measurements showed that the interaction of the solar wind with Mercury is more similar to the interaction with the Earth than with the Moon (K. Ozhil'vi, A. Lazarus, et al.). Estimates were received of the mass and radius of Mercury, which are in good concordance with ground measurements. Mercury obviously does not have an ionosphere. Pressure on the surface is estimated as about 10^{-8} mbar (H. Howard, J. Andersen et al.).

Flights were begun in 1972 to the distant planets of the Solar system. The Pioneer-10 started toward the giant of the Solar system, the planet Jupiter, on March 3, 1972. The spacecraft weighed about 258 kg. During 21 months of flight the spacecraft covered a distance of one billion kilometers /55
and on December 4, 1973, approached Jupiter, passing at a minimum distance of 131,400 km from the cloud tops covering the planet. The flight of the Pioneer-10 brought new, surprising data on the planet Jupiter. This primarily concerns the intensity and configuration of the magnetic field of the planet. The huge length of the magnetic field of Jupiter was recorded when the Pioneer-10 passed through the shock wave front at a distance of about 8 million kilometers during its approach to the planet. The velocity of solar wind particles

on the shock wave front fell from 450 to 200 km/sec, and the temperature increased from 10^4 to 10^6 degrees. The magnetopause--the boundary of Jupiter's magnetosphere--was recorded at a distance of about 7 million kilometers.

Jupiter's magnetic field differs substantially from its geomagnetic field: for Jupiter the former is more complex and seemingly consists of two parts--the inner (dipole) part with an intensity of about 4 Oe and a length of about 1.288 million kilometers, and the outer (non-dipole) part stretching from 3.38 to 10.5 million kilometers. The polarity of the magnetic field is inverse that of the Earth. The inner (dipole) field is displaced relative to the planet's axis of rotation by about 10°. The magnetic field on Jupiter's surface is eight times stronger than that of the Earth, and the total magnetic energy of Jupiter is 400 million times greater than the energy of the geomagnetic field. The radiation belts of Jupiter are the most intensive in the Solar system; their radiation dose exceeds by 100 times the fatal dose for man. The inner radiation belt of Jupiter, whose boundaries are 700,000 km from the surface of the planet, is largely similar to the inner radiation belt of the Earth. A completely new mechanism of the interaction of charged particles with the field operates in the outer magnetic field of Jupiter.

Jupiter has a huge proper rotation. The planet's rotation period for the midlatitudes is about 9^h55^m. The magnetic axis rotates with the same period relative to the axis of visible rotation. Because of the strong rotation the magnetic lines of force of the outer field are elongated, forming a long magnetic disk, and the charged particles are twisted into a flat equatorial layer--a cord. These particles produce in the cord an electric field, which flattens the magnetic field.

The appearance of the radiation belt of Jupiter is that of a compressed ring about 716,450 thousand kilometers thick, which is located at a distance from 2 to 10 million kilometers /56
from the boundary of the inner belt. The Pioneer-10 was subjected to hurricane exposure at each intersection of Jupiter's magnetic equator. From the outer radiation belt particles of high energy can penetrate to significant distances, reaching Earth orbits (E. Smith, M. Akuna, J. Simpson, J. Van Allen, et al.).

There were no television cameras on the Pioneer-10. Radar scanning device was used in place of them, by means of which many details of the surface of Jupiter were received. Powerful circulation processes were found in the atmosphere of Jupiter, chief of which is the formation of the famous "large red spot", discovered as early as 1664 and until now attracting the steady attention of astronomers. It was possible to show, by using ultraviolet photometry, that the atmosphere of Jupiter contains 82% hydrogen, 17% helium, as well as molecules of carbon and nitrogen entering the composition of complex compounds in the upper cloud layers--ammonium and methane. The mean temperature of the planet is close to -145°C, which is connected with the considerable dynamic mixing in the atmosphere. Data of infrared measurements show that the dark bands of Jupiter are hotter than the light-colored bands. Radio measurements showed that at an altitude of several hundred kilometers (from the upper boundary of clouds) a heat inversion is observed--the so-called thermal zones in which the temperature exceeds 0°C. This discovery attests to the fact that Jupiter has a relatively warm and long hydrogen atmosphere.

In constrast to the other planets of the Solar system, Jupiter generates 2.5 times more heat than it receives from the Sun. It is difficult to say how this similar thermal energy is formed. However, if it is assumed that Jupiter still continues to contract, then the decrease in the planet's diameter of 1 mm yearly is sufficient to obtain an observable heat yield through the liberated gravitational energy.

The Pioneer-10 passed behind one of the satellites of Jupiter--Io, and it was possible to establish from radiographic inspection that the Io satellite has not only an atmosphere but also an ionosphere. It is still difficult to say how the satellite effects the magnetosphere of Jupiter inside which its orbit takes place and what processes this causes, /57 but the Pioneer-10 instruments noticed one curious effect. They detected a bright cloud of atomic hydrogen stretching from Jupiter to the orbit of Io, which occupies two-thirds of the orbit of the satellite. On the other hand, a decrease in the intensity of high-energy protons was observed at the orbital distance of Io. Protons are obviously neutralized as they fall into the atmosphere of Io, turning into neutral atoms of hydrogen, whose glow was detected by the Pioneer-10 instruments in the form of a bright aureole accompanying Io as it moved around Jupiter.

After its flight past Jupiter, the Pioneer-10 went into a new trajectory in which it will leave our Solar system. Communication with the station will continue to 1979, when it will intersect with the orbit of Uranus. In 1987 the Pioneer-10 will pass beyond the boundaries of the Solar system, moving into interstellar space in the direction of the constellation Taurus.[1]

On April 6, 1973, another spacecraft, the Pioneer-11, started toward toward Jupiter, and reached the vicinity of the planet on December 5, 1974. Flying past Jupiter at a minimum distance of about 43,000 km, the Pioneer-11 transmitted to the Earth photographs of the polar regions of the planet, as well as pictures of the "big red spot," the largest one to that time obtained by scientists.

American scientists gave special attention to the pictures of the deep blue portions of the atmosphere of Jupiter over the northern and southern poles. These sections are

[1]In connection with this NASA placed in the body of the Pioneer-10 a gold plate with a symbolic depiction of Earth civilization as a friendly greeting to any other civilization, if a meeting with such a civilization should ever occur in the depths of the Universe.

speckled, round, red spots that "breathe." It is possible, as T? Gerels believes, that these bubbly masses are "convection cells"--outflows of gases rising from the region located under Jupiter's clouds.

Finally, it was possible to look directly into the eye of the "big red spot," whose diameter is about 36,000 km. A study of the circulation processes in the spot attests to the fact that it is an immense, centuries-old storm still in /58 the process of development. The spot consists of whirlwind clouds that rise above the cloud layer by 9 km. Rotating masses of gas have a sufficiently high temperature (dark red color in the center of the spot), which decreases toward the periphery (beige and white rings). However, how such an atmospheric disturbance arose and what maintains it for such a long time remains the secret of the planet Jupiter.

The vertical currents in the atmosphere of Jupiter are obviously less significant than the horizontal currents. It is possible that the wind velocity in Jupiter's atmosphere is about 580 km/hr.

A picture of the Callypso satellite, on which white clouds were detected, was received from the Pioneer-11. It can be assumed that these are polar caps. A noticeable influence was detected on the radiation belt of Jupiter as the main satellites of the planet--Io, Ganimeda and Europe--passed through it.

The trajectory of the Pioneer-11's flight was calculated such that the station would move toward Saturn and approach it in September 1979 after flying past Jupiter, under the effect of Jupiter's attraction.[1] It is planned that the Pioneer-11 will go inside the rings of Saturn and will fly at a distance of approximately 10,000 km from its surface. If the flight between Saturn and its rings is successful, then the next goal will be Titan, the main satellite of Saturn. Flights to the planets of the Solar system are one of the greatest manifestations of the human spirit, the strength of the human mind, the ineradicable scientific search, and the beauty of a knowledge of the cosmic depths of the Universe.

[1] At the present time this spacecraft has been named the "Pioneer-Saturn."